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Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. Patent application No. Demande de brevet n°

00204721.5

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

Hatten

I.L.C. HATTEN-HECKMAN

DEN HAAG, DEN
THE HAGUE, 24/08/01
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Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

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Method of analyzing a data set comprising a tubular structure

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Method of analyzing a data set comprising a tubular structure

The present invention relates to a method of analyzing an object data set comprising points in a multi-dimensional space, in which dataset a tubular structure occurs, said method comprising the following steps:

a. Choosing a starting position in or near the tubular structure;
b. Deriving a cutting plane through the tubular structure at the starting position,
c. Determining a number of points forming part of the surface of the tubular structure in the vicinity of the starting position; and
d. Calculating a gradient to the surface for each of said points.

The international patent application EP00/09505 (PHN 17.678) of the same applicant (not yet published) relates to a method of the type mentioned above. This method generally relates to the analysis of a tubular structure in a multi-dimensional space. According to the method described in the international patent application EP00/09505 a self-adjusting probe is defined for analysis of the object data set. The self-adjusting probe comprises a sphere and a plane through the center of the sphere. The sphere should be positioned such that the tubular structure intersects the sphere, at least partially. The plane should be oriented orthogonal to the tubular structure. When oriented correctly the self-adjusting probe enables semi-automatic shape extraction of tube-like geometry.

Such an object data set represents one or more properties of the object to be examined. The object data set notably relates to the density distribution in the object to be examined; in that case the data values are the local density values of (a part of) the object to be examined. The data values may also relate, for example, to the distribution of the temperature or the magnetization in the object. The multi-dimensional space is usually the three-dimensional space. The data values then relate to a volume distribution of the relevant property, for example, the density distribution in a volume of the object to be examined. The multi-dimensional space may also be two-dimensional. In that case the data values relate to a distribution of the relevant property in a plane through the object, for example the density distribution in a cross-section through the object.

The object data set can be acquired in a variety of ways. The object data set notably relates to a patient to be examined. Such an object data set can be acquired by means of various techniques such as 3D X-ray rotational angiography, computed tomography, magnetic resonance imaging or magnetic resonance angiography.

The method described in the international patent application EP00/09505 is particularly suitable for analyzing the structure of a blood vessel. Several physical characteristics of the blood vessel can be determined, such as the diameter thereof, which are crucial for diagnosis and a save treatment of for instance a stenosis or an aneurysm.

Currently the calculation of the above mentioned important step of orienting the cutting plane is based on a selection of surface points lying inside the sphere at a small distance from the plane. This is described in the article "Semi-Automatic Shape Extraction from Tube-like Geometry" by J. Bruijns, published in B. Girod, G. Greiner, H. Niemann, H.-P. Seidel (Eds.), Vision Modelling and Visualization 2000, Proceedings, November 22-24, 2000, Saarbruecken. In the example described in the article the surface of a blood vessel is represented by means of triangles (a known method which will be explained later). However, the known selection of surface points is rather arbitrary and may unintendedly include points associated with neighboring vessels. This directly leads to inaccuracies in the determination of the physical characteristics of the blood vessel under analysis.

The invention aims at providing a method of the type mentioned above which allows for a more accurate calculation of the physical characteristics of the tubular structure under analysis.

The method according to the invention thereto further comprises the characterizing steps of:

e) For each point determining a vector from the centre of the tubular structure to said point;
f) Determining the angle between said vector and the gradient at said point;
g) Adding said point to a selection of points if said angle is equal to or smaller than a predetermined ceiling value;
h) Using said selection of points to calculate an orientation for the cutting plane such that the direction thereof is as parallel as possible to the longitudinal axis of the tubular structure at the starting position;
i) Repeating steps a through h for a new starting position along the tubular structure, if necessary.

In a preferred embodiment the method further comprises the steps of: Defining a sphere which is at least partially intersected by the tubular structure; and performing steps e through g only for surface points lying inside the sphere. When the radius of said sphere is chosen wisely, e.g. slightly larger than the expected radius of the tubular structure under analysis, points within said sphere most likely belong to said tubular structure whereas points outside the sphere probably don't. Furthermore the reduction of the number of points taken into account during the calculation also increases the calculation speed.

In a further preferred embodiment the method steps e through g are performed only for points lying at a predetermined maximum distance from the cutting plane. This allows for a further advantageous reduction of the number of points involved in the calculation thus further increasing the calculation speed.

The invention also concerns a computer program to carry out the method according to the invention.

The invention will be further explained by means of the attached drawing, in which:

Figure 1 shows a cross section through two adjacent tubular structures under analysis by the method according to the invention.

In figure 1 a cross section is shown through two adjacent tubular structures, vessels 1 and 2. A sphere 3 is defined around vessel 1. The center of the sphere 3 and vessel 1 coincide and is indicated as c. Sphere 3 also partly intersects vessel 2.

According to the preferred embodiment the method according to the invention comprises the following steps. First a starting position is chosen in or near the tubular structure and a cutting plane is derived through the tubular structure at the starting position. These steps are also in more detail described in the international patent application EP00/09505, which entire document is incorporated herein by reference.

Next a number of points forming part of the surface of the tubular structure are defined in the vicinity of the starting position. In order to illustrate this step three points (also referred to as vertices) on the surfaces of the vessels are indicated. Point 4 is a surface point on vessel 1. Points 5 and 6 are surface points on vessel 2. In the relevant art several methods are known to define the surface of a vessel in an object data set. When the object data set comprises a volumetric representation of the object by means of voxels the surface of the vessel is defined by a set of boundary vessel voxels. This voxel set can be determined by first

separating the vessel voxels from the tissue voxels by means of known techniques, such as a 'region growing algorithm'. Next it is determined which of the vessel voxels lie adjacent to tissue voxels. These are referred to as boundary vessel voxels. Preferably this determination is performed by finding the face neighbors, i.e. neighbors which have one voxel face in common. As an alternative the surface of the vessel can be represented by surface triangles which can be generated by means of the so-called marching cubes algorithm which is known in the art. The marching cubes algorithm is for instance described in the article: "Marching Cubes: A High Resolution 3D Surface Construction Algorithm", by Lorensen and Cline, Computer Graphics, Vol. 21, No 4, July 1987.

In a next step for each of the vessel surface points a gradient is calculated. This is performed by means of standard techniques, which are among others described in the international patent application EP00/09505. The resulting gradients for points 4, 5 and 6 are respectively indicated as v4, v5 and v6.

In order to determine which of the three points should be included in the selection of points which are used for the calculation of the desired orthogonal orientation of the cutting plane the method comprises the following characterizing steps.

First for each point a vector is determined from the center of the tubular structure to said point. For point 4, said vector is designated as vc4. For point 5, said vector is designated as vc5. For point 6, said vector is designated as vc6.

Next for each surface point the angle is determined between each of said vectors and the gradient at said point. If said angle is equal to or smaller than a predetermined ceiling value said surface point is added to the above-mentioned selection of surface points, which are used to orient the cutting plane. A ceiling value can be set by a user or can be automatically set. From experiments a ceiling value between 50 and 70 degrees, for instance approximately 60 degrees, has proven to give reasonable results in the case of the current example relating to shape extraction for a blood vessel.

Returning now to figure 1 we will perform some calculations in order to illustrate the method according to the invention. Starting with point 4 the angle between v4 and vc4 is zero degrees. Let's assume that the ceiling value is chosen at 60 degrees. Point 4 is then added to the selection. This is rightly so because point 4 is a surface point on vessel 1, the vessel under analysis. However the angle between v5 and vc5 is more than 90 degrees. Point 5 will therefor under the current conditions be excluded from the selection. Again this is correct, since point 5 is a surface point of vessel 2, the neighboring vessel of the vessel investigated.

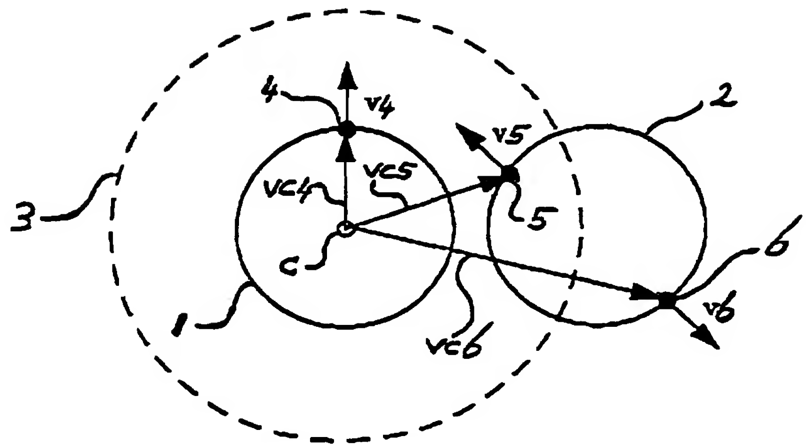

FIG.1

ABSTRACT:

The invention concerns a method of analyzing an object data set comprising points in a multi-dimensional space, in which dataset a tubular structure occurs, said method comprising the following steps:

a) Choosing a starting position in or near the tubular structure;
b) Deriving a cutting plane through the tubular structure at the starting position,
c) Determining a number of points forming part of the surface of the tubular structure in the vicinity of the starting position;
d) Calculating a gradient to the surface for each of said points.

The method further comprises the characterizing steps of:

e) For each point determining a vector from the center of the tubular structure to said point;
f) Determining the angle between said vector and the gradient at said point;
g) Adding said point to a selection of points if said angle is equal to or smaller than a predetermined ceiling value;
h) Using said selection of points to calculate an orientation for the cutting plane such that the direction thereof is as parallel as possible to the longitudinal axis of the tubular structure at the starting position;
i) Repeating steps a through h for a new starting position along the tubular structure, if necessary.

The invention also refers to a computer program to carry out the method according to the invention.

Fig.

CLAIMS:

1. A method of analyzing an object data set comprising points in a multi-dimensional space, in which dataset a tubular structure occurs, said method comprising the following steps:

a) Choosing a starting position in or near the tubular structure;
b) Deriving a cutting plane through the tubular structure at the starting position,
c) Determining a number of points forming part of the surface of the tubular structure in the vicinity of the starting position;
d) Calculating a gradient to the surface for each of said points;

characterized in that the method further comprises the steps of:

e) For each point determining a vector from the center of the tubular structure to said point;
f) Determining the angle between said vector and the gradient at said point;
g) Adding said point to a selection of points if said angle is equal to or smaller than a predetermined ceiling value;
h) Using said selection of points to calculate an orientation for the cutting plane such that the direction thereof is as parallel as possible to the longitudinal axis of the tubular structure at the starting position;
i) Repeating steps a through h for a new starting position along the tubular structure, if necessary.

2. Method according to claim 1, further comprising the steps of: defining a sphere, which is at least partially intersected by the tubular structure; and performing steps e through g only for points lying inside the sphere.

3. Method according to claim 1 or 2, wherein steps e through g are performed only for points lying at a predetermined maximum distance from the cutting plane.

4. A computer program to carry out the method according one or more of the preceding claims.

It is noted that the angle between v6 and vc6 appears to be smaller than 60 degrees. Point 6 would unintendedly be added to the selection, since point 6 is a surface point of vessel 2. This can be prevented by adding another criterion relating to the selection of vertices. A useful second criterion is that only surface points lying inside sphere 3 should be included in the selection. From figure 1 it is clear that point 6 does not meet this criterion and would therefor not be included in the selection after all.

It is noted that a useful third criterion would be to only perform steps e through g for points lying at a predetermined maximum distance from the cutting plane. When de object data set comprises surface triangles, a ceiling value for this distance can e.g. be derived form the length of the triangle edges (see also the above mentioned article by Bruijns).

The order in which the three criteria according to the method according to the invention are implemented may be varied.

The thus created selection of surface points is now used to orient the cutting plane such that the direction thereof is as parallel as possible to the longitudinal axis of the tubular structure at the starting position. An example of this calculation is described in the article mentioned above, which document is entirely incorporated herein by reference. The above steps of the method according to the invention can be repeated for each new starting position along the tubular structure, if necessary.

Now the method of the invention is explained, a skilled person will be able to translate the steps of the method into a computer program to carry out the method.

Summarizing the invention refers to a method for analyzing an object data set in a multi-dimensional space comprising a tubular structure. This method is especially useful in the field of medical diagnostics and treatment, where the object notably is a patient to be examined. All kinds of tubular structures can be analyzed, such as blood vessels, but also brain cell or neuron cell structures. In analyzing blood vessels the method according to the invention allows for an accurate determination of the size and diameter of a blood vessel which is essential for the right diagnosis of e.g. stenosis or an aneurysm and the save treatment thereof.

The invention is of course not limited to the described or shown embodiment, but generally extends to any embodiment, which falls within the scope of the appended claims as seen in light of the foregoing description and drawings.